Parallel wave sound analysis
based on hierarchical domain decomposition method

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Abstract

We are investigating a large-scale non-steady wave sound analysis method based on the parallel finite element method by developing ADVENTURE_Sound as an opensource software. The iterative domain decomposition method is employed in the analysis code as a parallel technique. We have confirmed that the non-steady wave sound analysis code is very high-accuracy with errors within the allowable range in a numerical analysis.

Keywords: Wave sound analysis, Finite element method, Domain decomposition method, Huge-scale analysis.

1. Introduction

There is growing demand for advanced sound design, such as noise reduction and high-quality indoor and outdoor acoustic environment. It is thus necessary to understand the sound pressure distribution with high accuracy. There is also a need to reduce the costs of designing acoustic spaces [1] and electrical equipment for noise-suppression equipment. Acoustic analysis techniques have been used for the acoustic design of concert halls and noise suppression equipment due to improvements in computer hardware and software performance.

2. Governing equations and algorithm for parallel computing

In ADVENTURE_Sound, the wave-sound analysis is considered. To derive a weak form, the Galerkin method is applied to the Helmholtz equation [1]. The finite element approximation and discretized, the following equation is obtained:

$$\iiint_{\Omega_e} \nabla \Phi_h \cdot \nabla {\Phi_h}^* d\Omega_e - \frac{j\omega\rho}{Z_n} \iint_{\Gamma_e} \Phi_h {\Phi_h}^* d\Gamma_e - k^2 \iiint_{\Omega} \Phi_h {\Phi_h}^* d\Omega_e = 0. \quad (1)$$

where Φ is the speed potential that is the unknown function. k and ω are the wave number and angular frequency, ρ is the medium density, and Z_n is the specific acoustic impedance.

The equation contains complex numbers and becomes a complex symmetric matrix. In the present study, the speed potential Φ is obtained using the conjugate orthogonal conjugate gradient (COCG) method. The finite element approximation (1) is rewritten as $Ku = f$ by the coefficient matrix K, the unknown vector u, and the right-hand side vector f. Next, Ω is divided into N subdomains (Eq. (2)). Eq. (3) and (4) are obtained from Eq. (2) [2].

$$\begin{bmatrix} K_{II}^{(1)} & 0 & 0 & K_{IB}^{(1)} R_B^{(1)\mathrm{T}} \\ 0 & \ddots & 0 & \vdots \\ & & K_{II}^{(N)} & K_{IB}^{(N)} R_B^{(N)\mathrm{T}} \\ 0 & 0 & & \\ R_B^{(1)} K_{IB}^{(1)\mathrm{T}} & \cdots & R_B^{(N)} K_{IB}^{(N)\mathrm{T}} & \sum_{i=1}^{N} R_B^{(i)} K_{BB}^{(i)} R_B^{(i)\mathrm{T}} \end{bmatrix} \begin{bmatrix} u_I^{(1)} \\ \vdots \\ u_I^{(N)} \\ u_B \end{bmatrix} = \begin{bmatrix} f_I^{(1)} \\ \vdots \\ f_I^{(N)} \\ f_B \end{bmatrix} \tag{2}$$

$$K_{II}^{(i)} u_I^{(i)} = f_I^{(i)} - K_{IB}^{(i)} u_B^{(i)} \quad (i = 1, \ldots, N) \tag{3}$$

$$\left\{ \sum_{i=1}^{N} R_B^{(i)} \left\{ K_{BB}^{(i)} - K_{IB}^{(i)\mathrm{T}} \left(K_{II}^{(i)} \right)^{-1} K_{IB}^{(i)} \right\} R_B^{(i)T} \right\} u_B = \sum_{i=1}^{N} R_B^{(i)} \left\{ f_B^{(i)} - K_{IB}^{(i)T} \left(K_{II}^{(i)} \right)^{-1} f_I^{(i)} \right\} \tag{4}$$

where ${f_B}^{(i)}$ is the right-hand vector for u_B, and $\left(K_{II}^{(i)}\right)^{-1}$ is the inverse matrix of $K_{II}^{(i)}$. Equation (4) is referred to as an interface problem and is an equation for satisfying the continuity between domains in the domain decomposition method. For simplicity, rewrite Eq. (5) as follows:

$$\begin{aligned} S u_B &= g, \\ S &= \sum_{i=1}^{N} R_B^{(i)} S^{(i)} R_B^{(i)T}, \quad S^{(i)} \\ &= K_{BB}^{(i)} - K_{IB}^{(i)T} \left(K_{II}^{(i)} \right)^{-1} K_{IB}^{(i)}. \end{aligned} \tag{5}$$

3. Numerical example

For examining ADVENTURE_Sound on a real-world problem, we model the environ-ment of acoustic experiments. The computations are performed on a 16-node (62-core) PC cluster (Intel(R) Xeon(R) CPU E5-2650L; 1.80 GHz; L2 20480 KB) with 32 GB RAM per node. The simulation statistics and the numerical are shown in Table 1 and 2, respectively. More detail thins will be shown at the conference.

Table 1 Simulation Statistic

Frequency	442[Hz]
No. of Elements	911,133
No. of DOF	1,249,959
Platform	10-node workstation cluster with Intel(R) Xeon(R) CPU E5-2650L, 1.8 GHz
No. of cores per node	16
No. of nodes	8
Main memory per node	32 [GB/node]

Table 2 Numerical result

Elapsed time	509.153 [s]
Memory requirements	0.26 [GB/node]

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References

1. Amane Takei and Akihiro Kudo: Over 100 Million Degrees of Freedom Scale Wave Sound Analysis Based on Parallel Finite Element Method,.12:2(2020), 76-84. (in Japanese)
2. A. Takei, S. Sugimoto, M. Ogino, S. Yoshimura, H. Kanayama: Full Wave Analyses of Electromagnetic Fields with an Iterative Domain Decomposition Methodm, IEEE Transactions on Magnetics, 46:8 (2010), 2860-2863.

Authors Introduction

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Prof. Akihiro Kudo

Akihiro Kudo was received was received Ph.D. of engineering from Nagaoka University of Technology, 2007. He started working as an Assistant Professor in the Department of Electrical and Electronic Engineering at Tomakomai National College of Technology in 2007, and has held the position of Associate Professor there since 2011, up to the present.
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